W boson mass and width measurements at the Tevatron

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Motivation

Derive W mass from precisely measured electroweak quantities

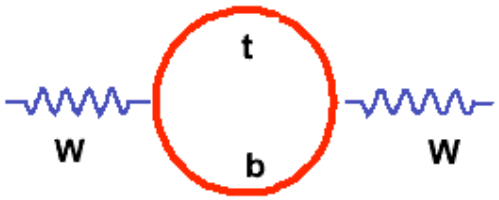
Measured to 0.015%

Measured to 0.002%

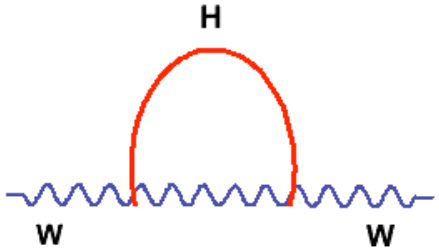
$$M_W^2 = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}G_F}\,\frac{1}{(1-(M_W^2/M_Z^2))}\,\frac{1}{(1-\Delta r)}$$

Measured to 0.0009%

Δr: O(3%) radiative corrections dominated by *tb* and Higgs loops



$$\Delta M_W \propto M_{top}^2$$



$$\Delta M_W \propto \ln M_H$$

M_H can be constrained by precisely measuring M_W and M_{top} :

$M_H = 85^{+39}_{-28}$ GeV (EWWG) (M_H < 166 (95% CL))

Γ_W is known very precisely in Standard Model (2MeV)

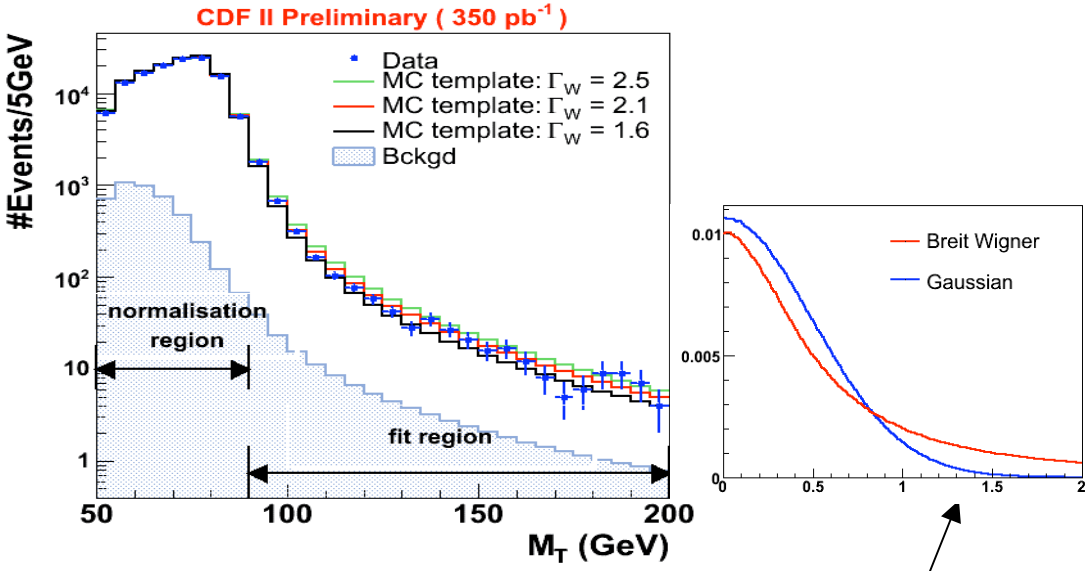
New physics could be seen as disagreement between precision measurement and theory.

Measurement Strategy

- use leptonic decay modes ; $p\bar{p} \rightarrow W \rightarrow \ell\nu$
- transverse quantities used
- Use M_T to extract both mass and width;

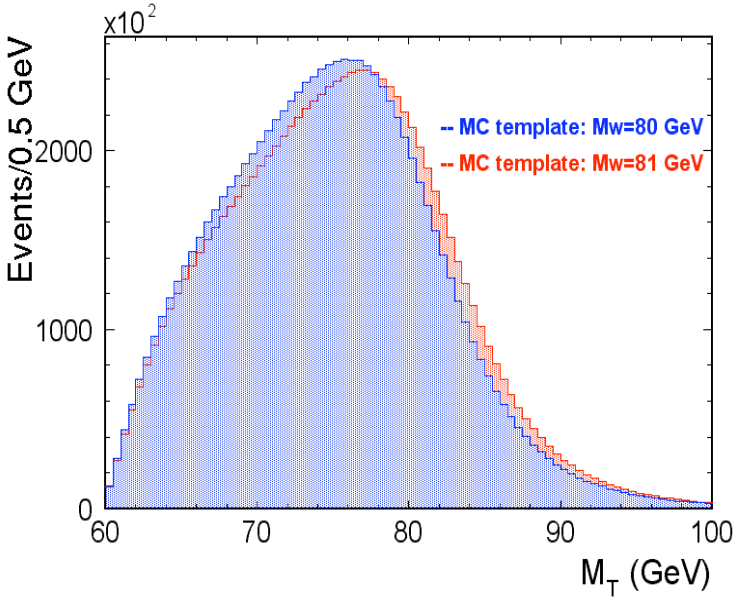
$$M_T = \sqrt{2p_T^{\ell}p_T^{\nu}(1-\cos(\Delta\Phi^{\ell\nu}))}$$

Γ_W



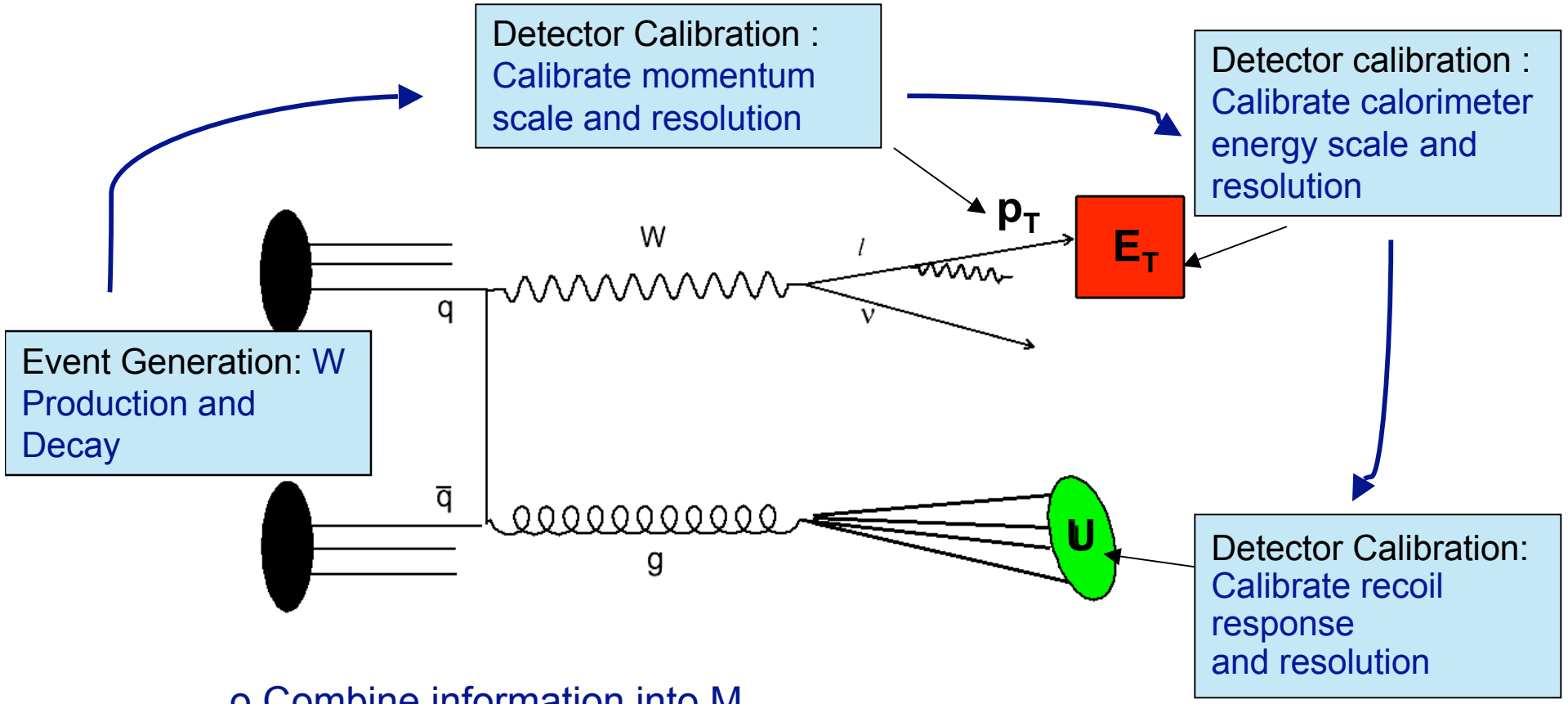
- Fit in region 90 - 200 GeV
- Exploit the slower fall off of Breit Wigner lineshape compared to gaussian resolution

M_W



- Fit in region 65 - 90 GeV

Measurement Steps



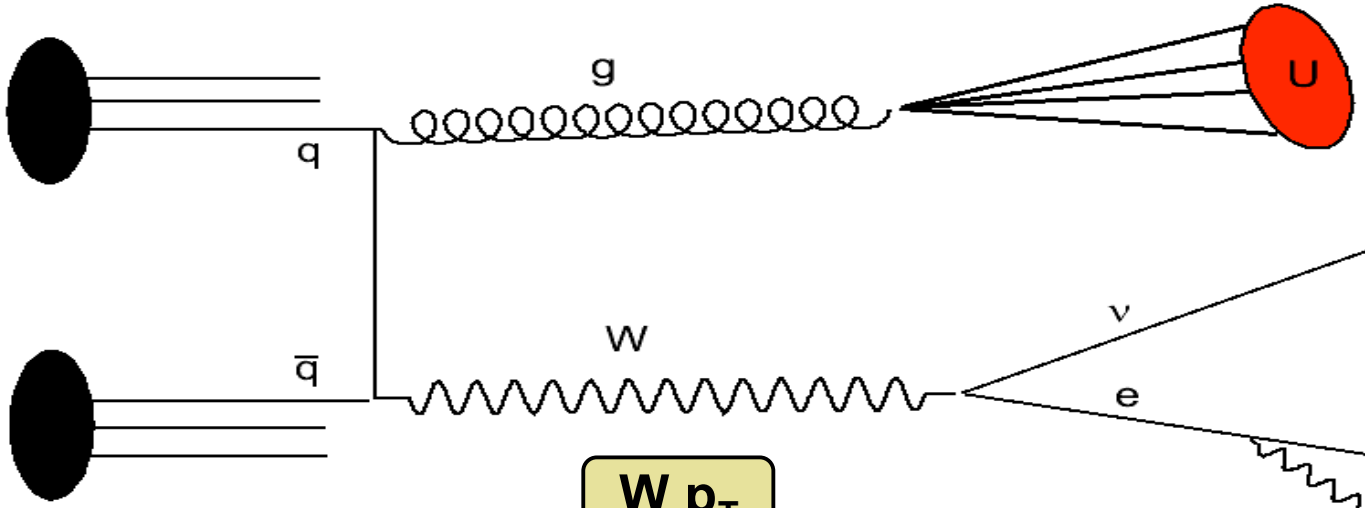
- Combine information into M_T,

$$M_T = \sqrt{2p_T^{\ell}p_T^{\nu}(1-\cos(\Delta\Phi^{\ell\nu}))}$$

where p_T^{ν} inferred from missing transverse energy, $\vec{p}_T^{\,\nu} = -(\vec{p}_T^{\,\ell} + \vec{U})$

- Add backgrounds to MC templates.
- Fit for Mass/Width

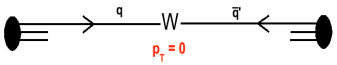
Event Generation: W Production and Decay



W p_T

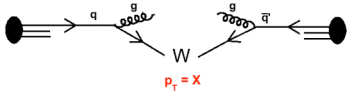
QED

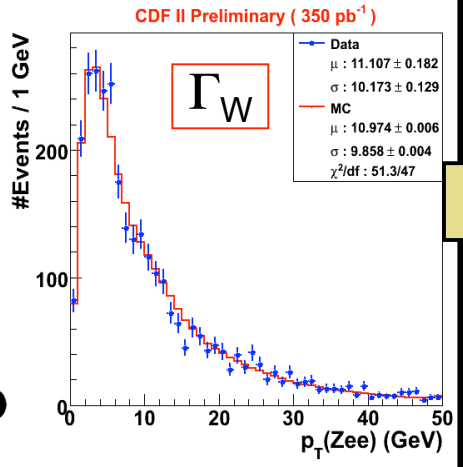
- Use a LO generator
- interfaced with the PDF set (CTEQ6M)
- This produces a W with zero p_T.



+

- Use RESBOS.
- Tune RESBOS parameter g2 to our $Z \rightarrow ll$ data
- theoretical calculation Z $p_T \rightarrow$ Wp_T.





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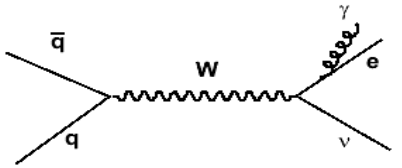
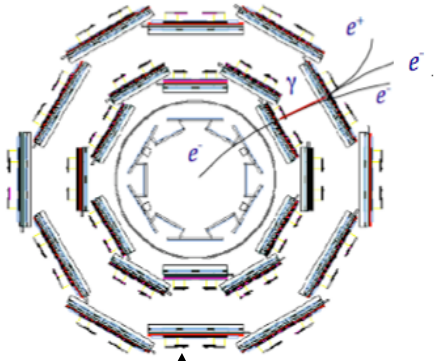
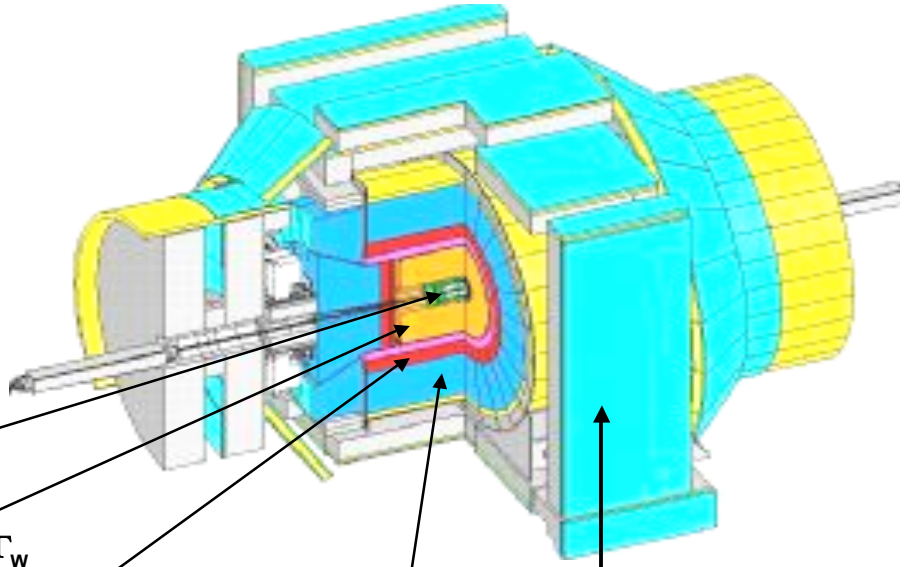
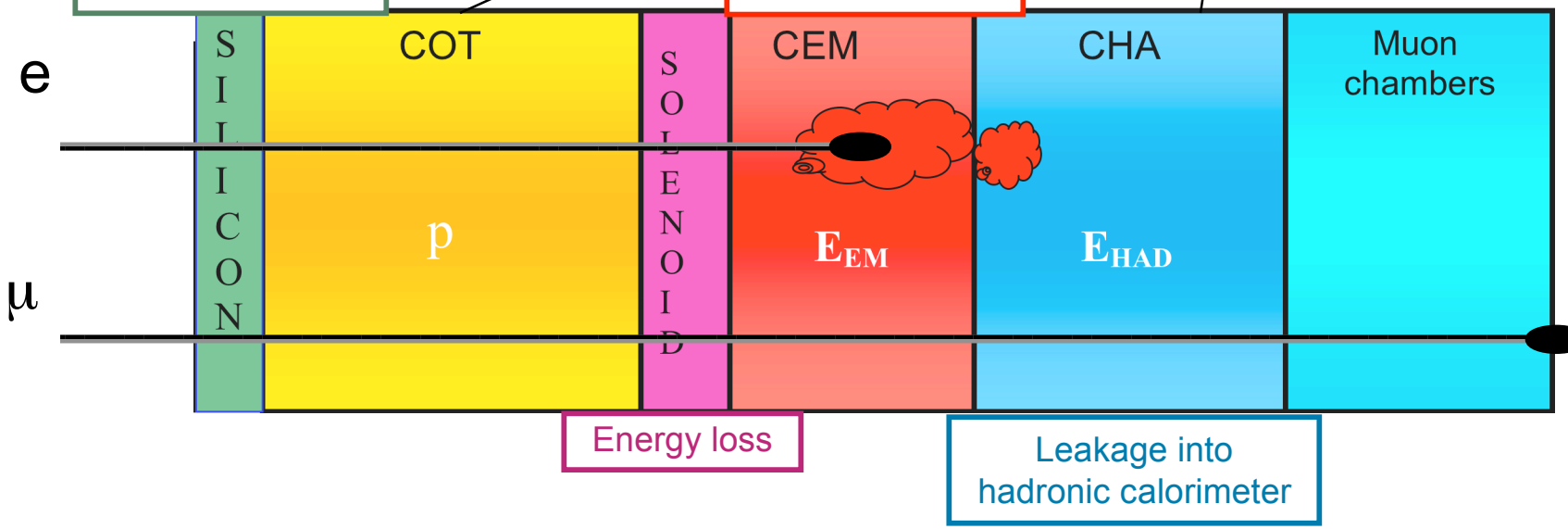
- Also interfaced with the WGRAD(M_W) /Berends Kleiss(Γ_W) program which adds upto one photon from the charged lepton.



Particles in CDF detector







Momentum Scale and Resolution

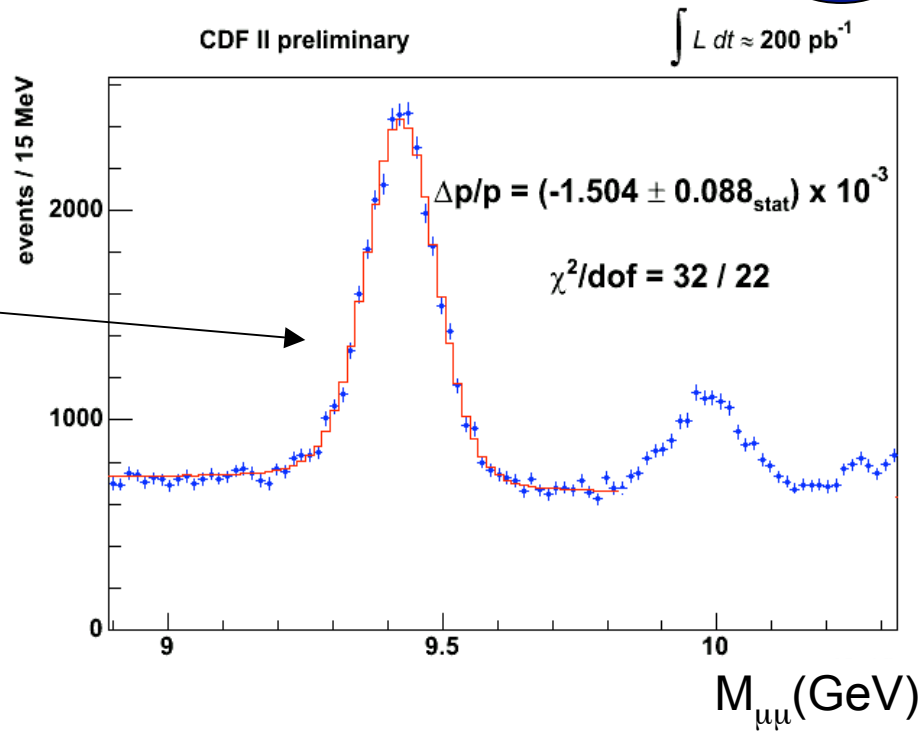
Momentum scale set using:

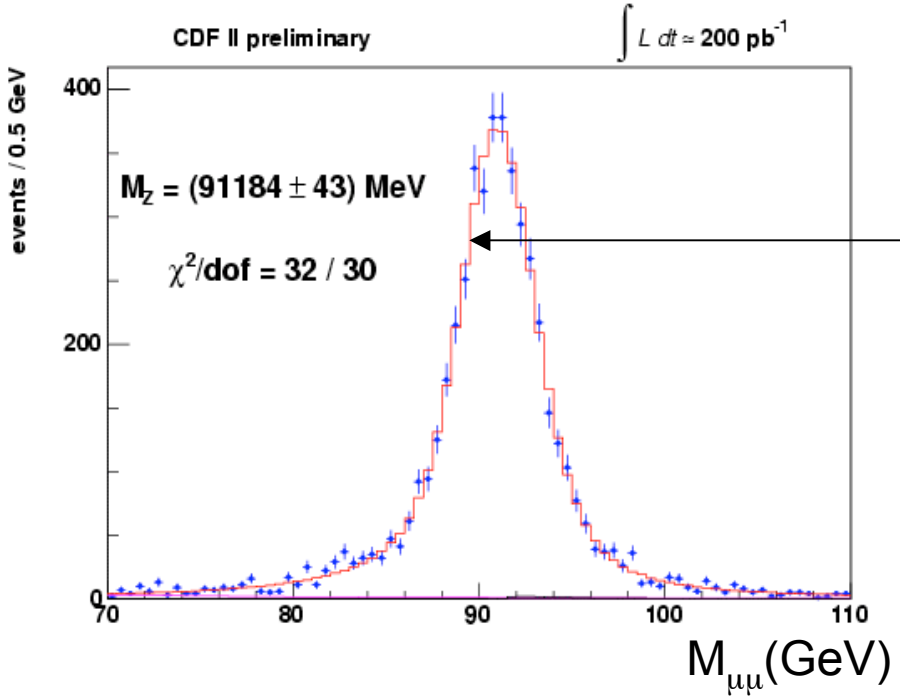
- $J/\Psi \rightarrow \mu\mu$ data ($M_{J/\Psi} \sim 3$GeV)
- $\Upsilon \rightarrow \mu\mu$ data ($M_{\Upsilon} \sim 10$GeV)

$\Upsilon(1S)$

Cross -checked using:

- $Z \rightarrow \mu\mu$ data ($M_Z \sim 91$GeV)



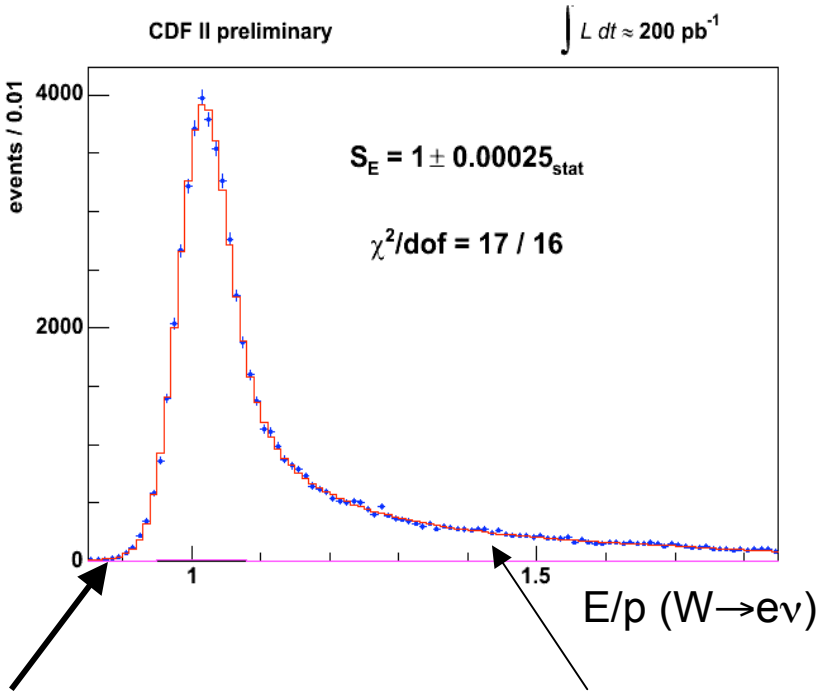


Z mass in good agreement with world average value (91188±2 MeV)

Momentum resolution obtained from width of distributions.

Energy scale and resolution

Fit to the E/p distribution in W→eν data



E

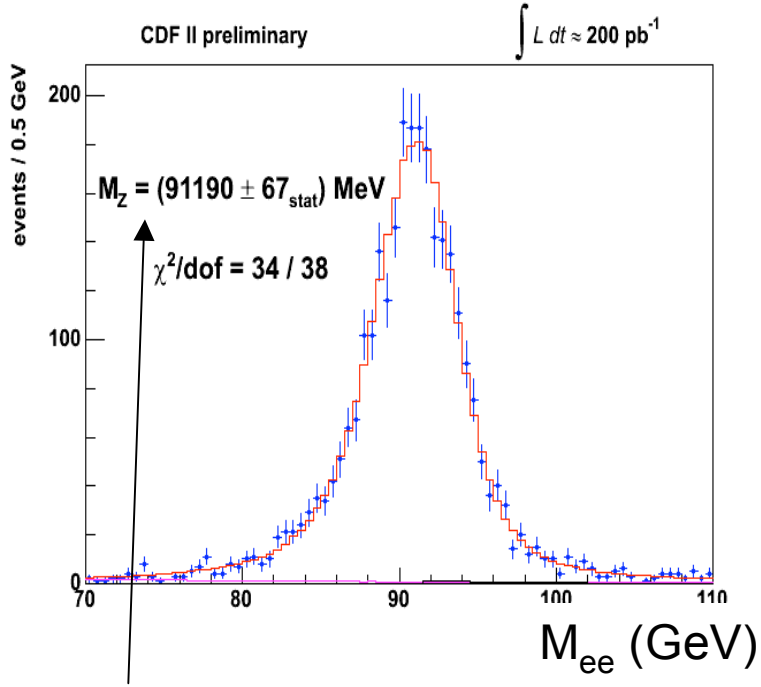
p

At low E/p, E < p due to energy leakage into hadronic calorimeter

At high E/p , p < E due to brehmsstrhalung

Fit to the invariant mass of the Z in Z→ee data

-provides powerful cross-check

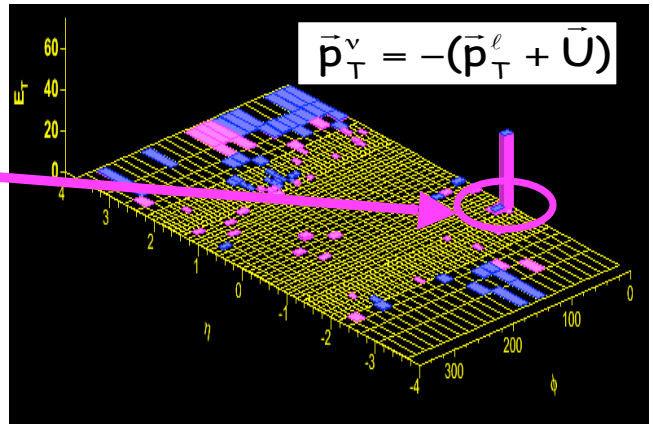


Z mass in good agreement with world average (91188±2 MeV)

The Recoil Model

Recoil defined as vector sum over energy in all calorimeter towers excluding those containing/neighbouring the lepton(s).

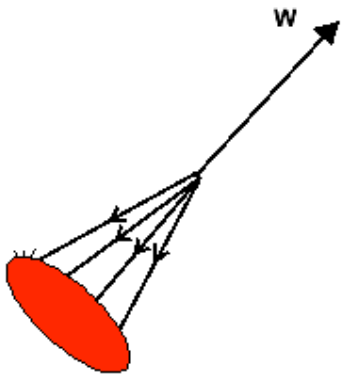
$$\underline{U} = (u_x, u_y) = \sum_{\text{towers}} E \sin\theta(\cos\phi, \sin\phi)$$



There are 3 main contributions to the recoil;

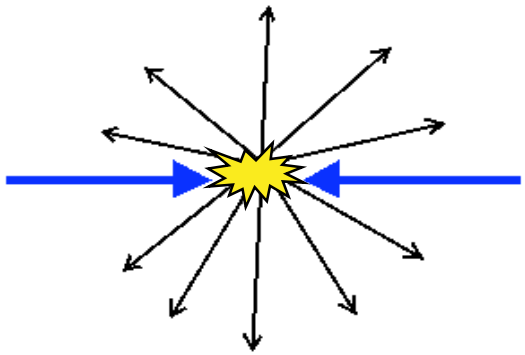
QCD

Gluon jet recoiling off the boson



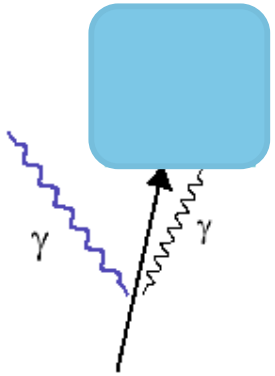
Underlying energy

Multiple interactions, spectator quark interactions and remnants of the ppbar collision.



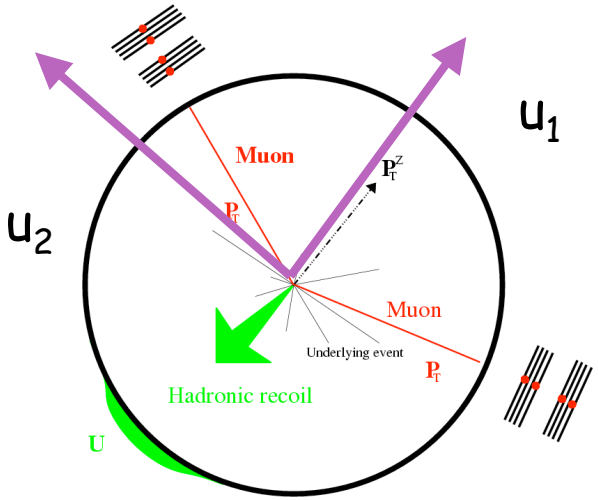
Bremsstrahlung

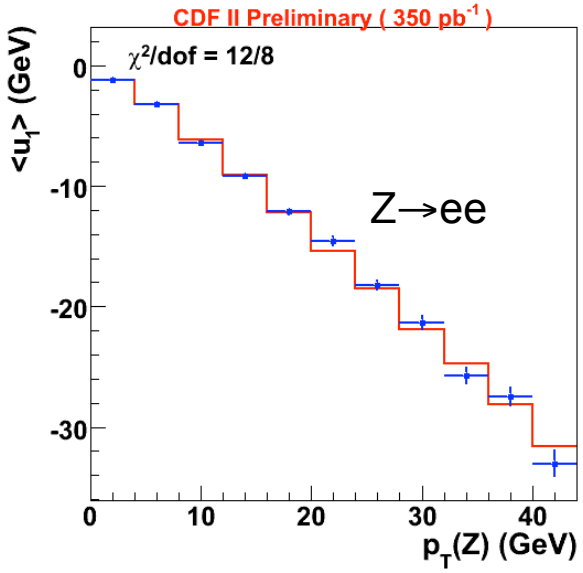
Photons emitted by lepton that do not end up in the excluded region



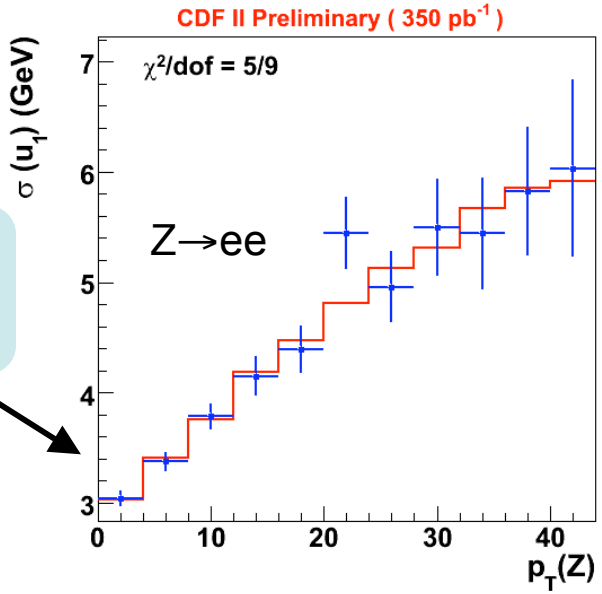
The Recoil Model

- Pythia/Herwig not accurate enough.
- ad-hoc parametric model.
- Model recoil using $Z \to \ell\ell$ and minimum-bias data.





Dominated by resolution of underlying event.



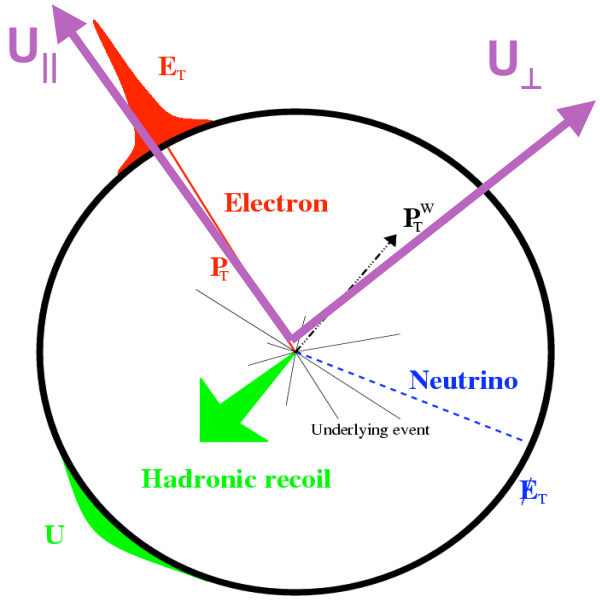
Dominated by jet resolution

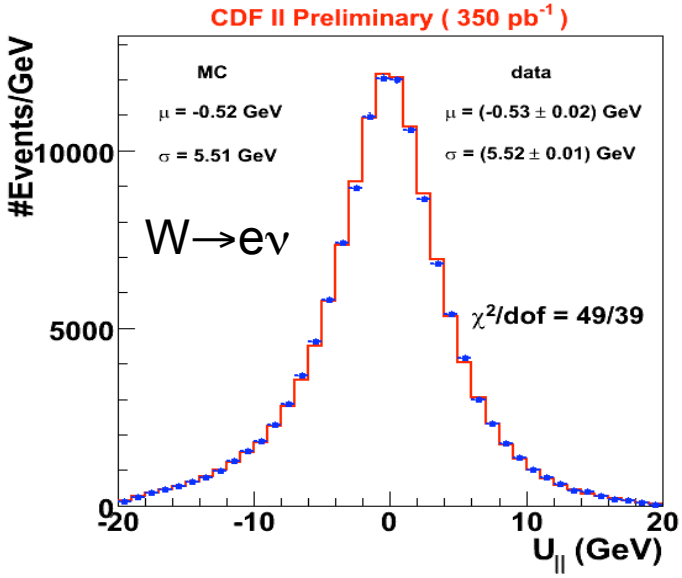
Recoil Model: W comparison

Recoil model for Zs is then applied to Ws.

In W events, recoil is resolved into 2 directions;

- $U_{||}$: parallel to p_T(lepton)
- $U_{\perp}$: perpendicular to p_T(lepton)





$$M_T \approx 2p_T - U_{||}$$

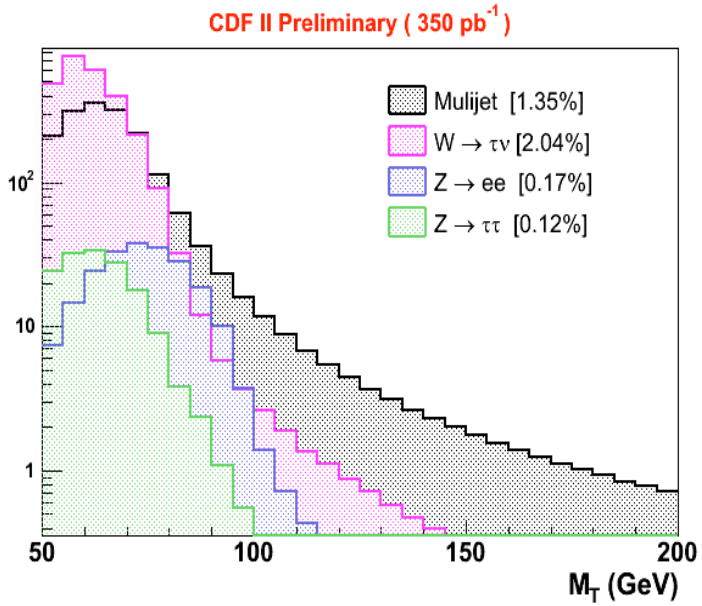
Bias in $U_{||}$ directly biases M_T

Backgrounds

- Backgrounds added to MC templates
- Electroweak backgrounds taken from full MC
- QCD backgrounds taken from data.

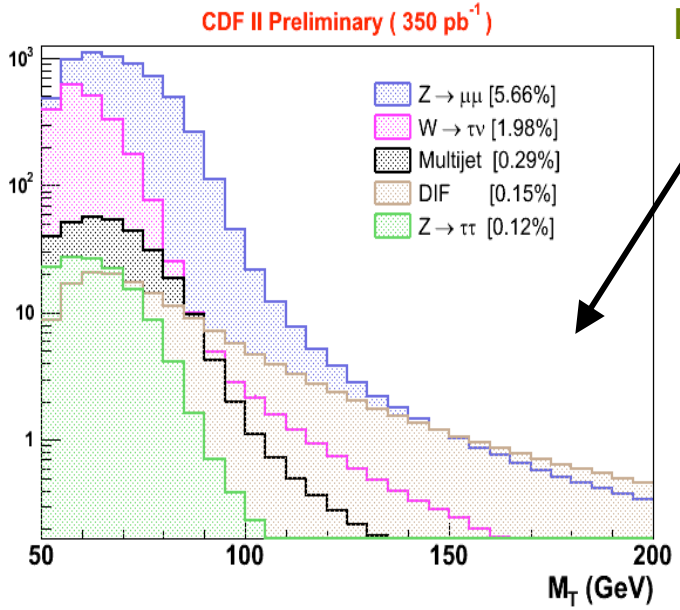
Electron channel

- multijet, where one of the jets fakes an electron and the other is mismeasured.



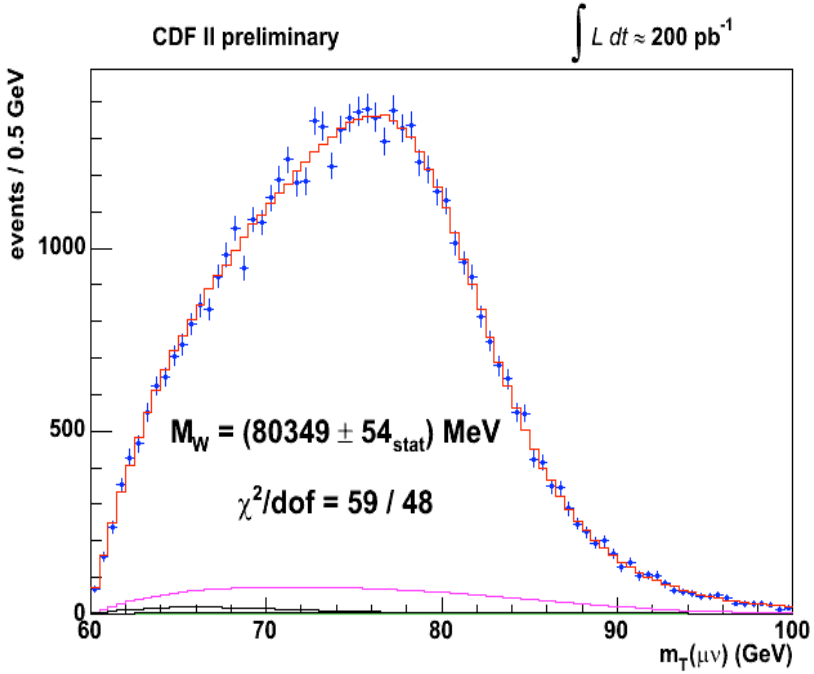
Muon channel

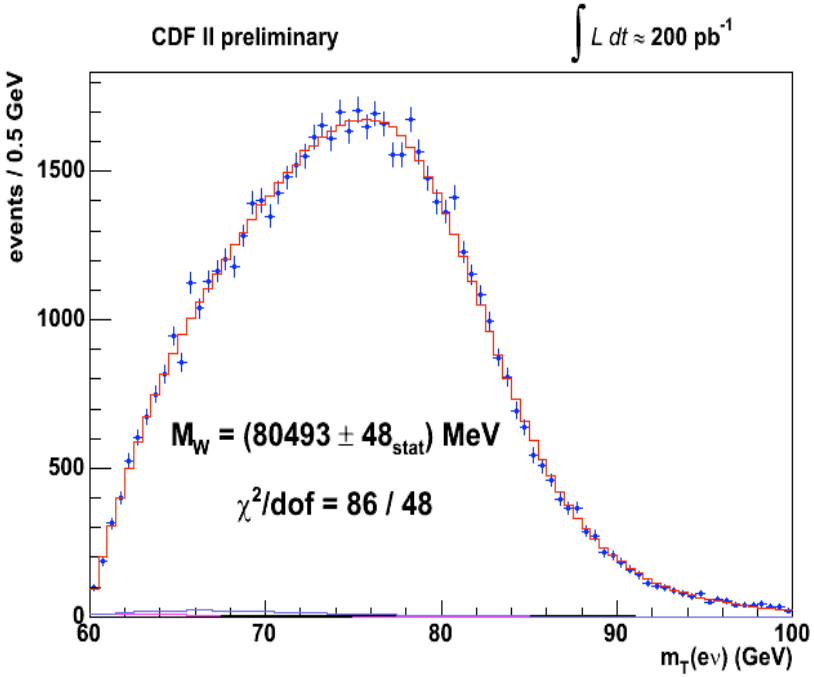
- decay in flight(DIF), kaon/pion decaying to μν pair.



Flat in the high M_T region.

W Mass fits





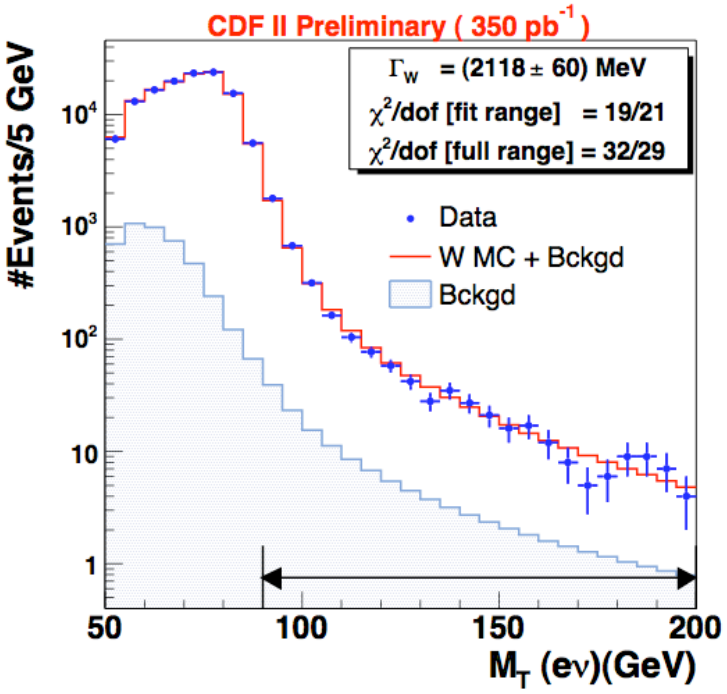
M_W = 80417 ± 48 (stat + syst) MeV

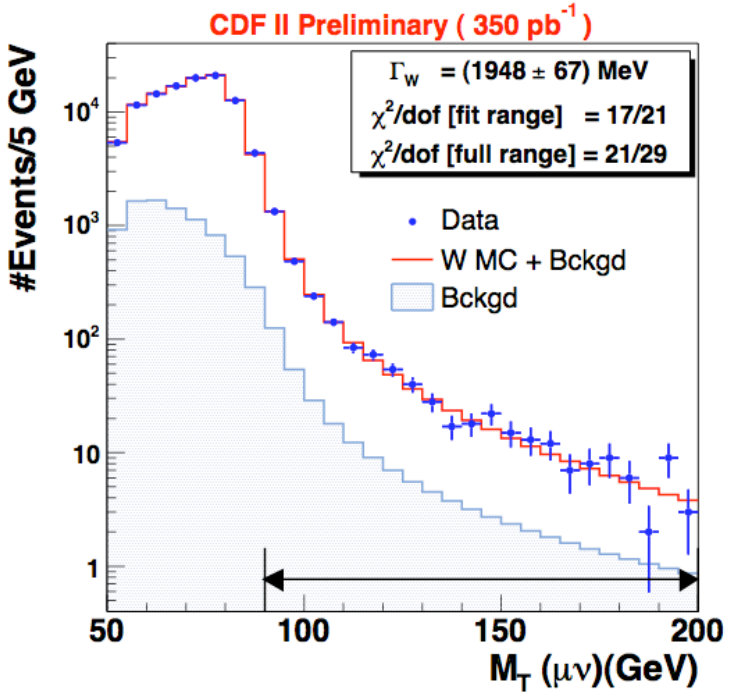
e + μ combination P(χ^2) = 7%

Include fits to p_T^{ℓ} and p_T^{ν}:

M_W = 80413 ± 48 (stat + syst) MeV

W Width fits





Γ_W = 2032 ± 71(stat + syst) MeV

Combination p-value = 20%

Systematics Table

M_W systematics

CDF II preliminary L = 200

m_T Uncertainty [MeV]	Electrons	Muons	Comm
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{\parallel}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

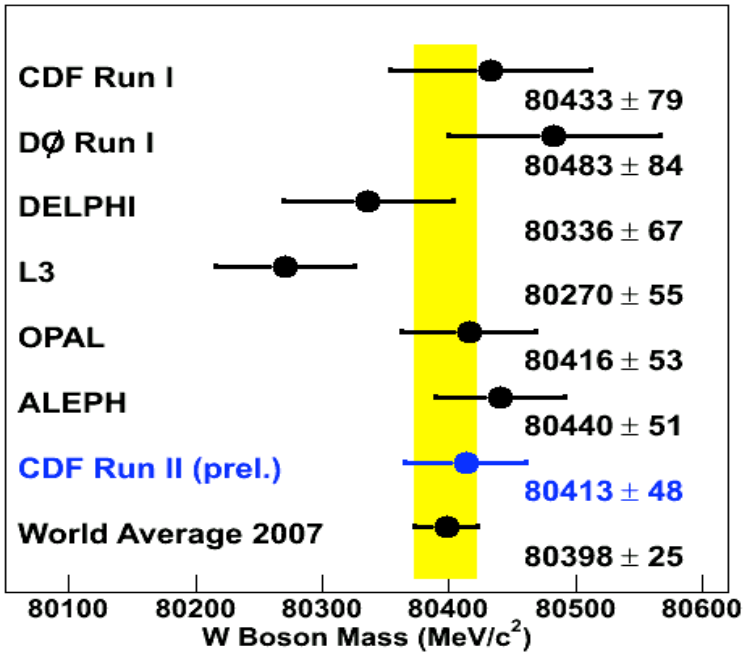
Γ_W systematics

CDF Run II Preliminary (350 pb^{-1})

	$\Delta\Gamma_W$ [MeV]		
	Electrons	Muons	Common
Lepton Scale	21	17	12
Lepton Resolution	31	26	0
Simulation	13	0	0
Recoil	54	49	0
Lepton ID	10	7	0
Backgrounds	32	33	0
$p_T(W)$	7	7	7
PDF	16	17	16
QED	8	1	1
W mass	9	9	9
Total systematic	78	70	23
Statistical	60	67	0
Total	98	97	23

Results

World's most precise single measurements!

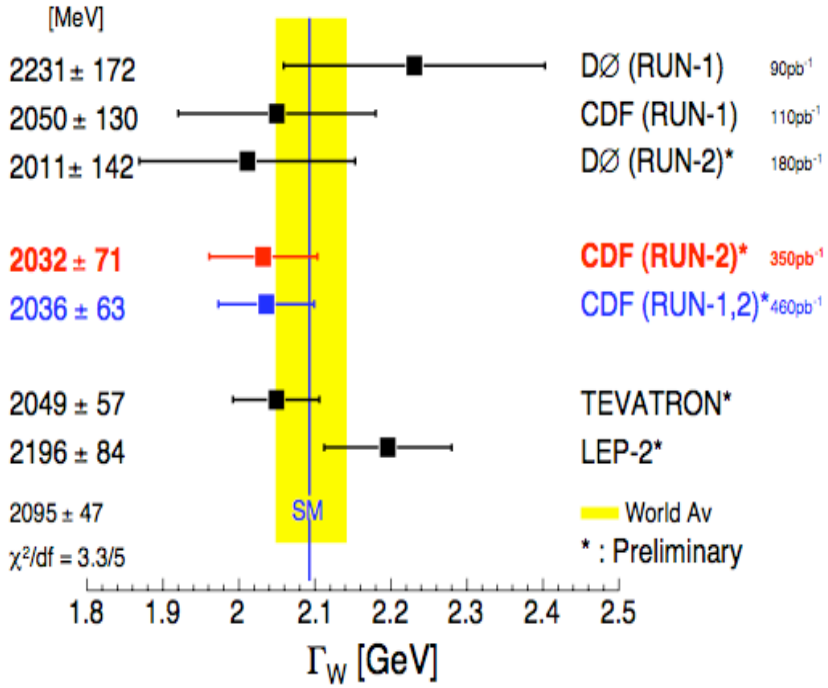


Central value increases by 6 MeV:

80392 → 80398 MeV

Reduces uncertainty on world average by 15%:

29 → 25 MeV



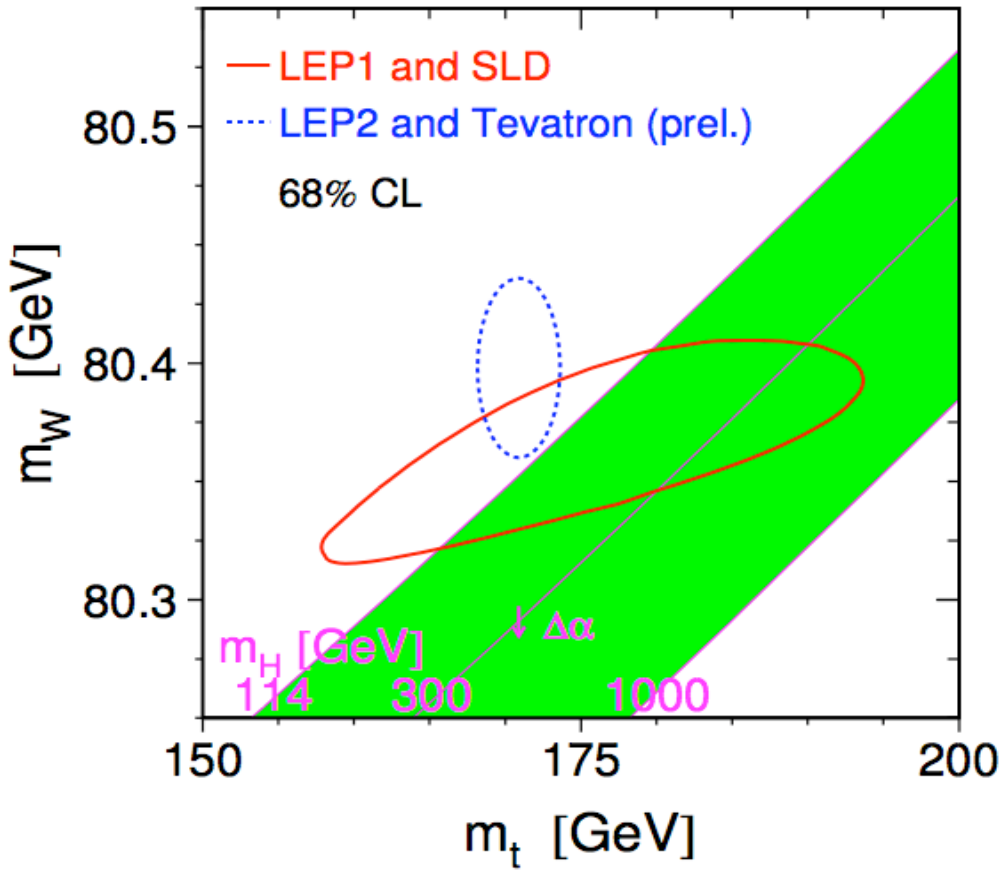
Central value decreases by 44 MeV:

2139 → 2095 MeV

Reduces uncertainty on world average by 22%

60 → 47MeV

Electroweak fits



Summer 2006

$m_H = 85^{+39}_{-28}$ GeV

$m_H < 166$ GeV @ 95% C.L.

Including New CDF M_W :

$m_H = 80^{+36}_{-26}$ GeV

$m_H < 153$ GeV @ 95% C.L.

Including New M_{top} :

Later this session….

Summary

- M_W : **80413 ± 48 MeV (stat + syst)**
- Γ_W: **2032 ± 71 MeV (stat + syst)**

Both are the world's most precise single measurements!

- New M_W further constrained Higgs mass, lighter Higgs is preferred!

Mass of Higgs has moved further into directly excluded region

- Analyses utilised 200 pb^{-1} (Mw) and 350 pb^{-1} (Γ_W), both CDF and DØ already have ~2 fb^{-1} on tape.
- **Expect improved mass/width measurements to further test the SM and constrain Higgs mass.**